

EXPERIMENTAL AND KINETIC STUDY ON CO<sub>2</sub> CATALYTIC GASIFICATION  
OF BIOMASS CHAR USING CONVENTIONAL AND MICROWAVE HEATING

POOYA LAHIJANI AMIRI

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## LIST OF ABBREVIATIONS

AAEM	Alkali and alkaline earth metal
BET	Brunauer-Emmett-Teller
BJH	Barrett-Joyner-Halenda
CGSM	Changing grain size model
DTF	Drop tube furnace
EDX	Energy dispersive X-ray
FB	Fluidized bed
FTIR	Fourier transform infrared
GC	Gas chromatograph
GM	Grain model
HHV	Higher heating value
L-H	Langmuir-Hinshelwood
MH	Microwave heating
MRPM	Modified random pore model
NDM	Normal distribution function model
NMR	Nuclear magnetic resonance
PEFR	Pressurized entrained flow reactor
PID controller	Proportional-integral-derivative controller
RPM	Random pore model
S-MRPM	Shifted modified random pore model
SCM	Shrinking core model

SE	Secondary electrons
SEM	Scanning electron microscope
TB	Thermobalance
TCD	Thermal conductivity detector
TF	Tube furnace
TGA	Thermogravimetric analyzer
TH	Thermal heating
VRM	Volume reaction model
XRD	X-ray diffraction
XRF	X-ray fluorescence

## LIST OF SYMBOLS

$a$	Time at firing (min)
$A$	Pre-exponential factor ( $\text{min}^{-1}$ )
$b$	Time at 6/10 of maximum temperature (min)
$c$	Time to get maximum temperature (min)
$c$	Empirical constant in M-RPM
$C_f$	Free carbon active site
$CQ_{t_i}$	Volumetric concentration of CO at time $t_i$ (%)
$C_{pW}$	Specific heat of water (J/kg.K)
$C_{strong}$	Strong chemisorbed CO <sub>2</sub> (mg/g)
$C_{total}$	Total chemisorbed CO <sub>2</sub> (mg/g)
$C_{weak}$	Weak chemisorbed CO <sub>2</sub> (mg/g)
$E_a$	Activation energy (J/mol)
$E^{app}$	Apparent activation energy (J/mol)
$E^{int}$	Intrinsic activation energy (J/mol)
GHSV	Gas hourly space velocity ( $\text{h}^{-1}$ )
$I_D$	Intensity of the $D$ band in Raman spectroscopy
$I_G$	Intensity of the $G$ band in Raman spectroscopy
$k$	Reaction rate constant
$k_0$	Pre-exponential factor ( $\text{min}^{-1}$ )
$k_1$	Reaction rate constant in L-H
$K_2$	Equilibrium adsorption constant in L-H

$K_3$	Equilibrium adsorption constant in L-H
$k_{GM}$	Reaction rate constant of grain model ( $\text{min}^{-1}$ )
$k_{SCM}$	Reaction rate constant of shrinking core model ( $\text{min}^{-1}$ )
$k_{VRM}$	Reaction rate constant of volume reaction model ( $\text{min}^{-1}$ )
$L_0$	Pore length
$m$	Shape factor
$M_{0, CO_2}$	Initial moles of $CO_2$ introduced to the char bed (mmol)
$m_{Ash}$	Mass of ash (mg)
$m_{ECW}$	Equivalent calorimeter mass of water (kg)
$m_s$	Mass of sample (kg)
$m_{WC}$	Mass of water in cylinder (kg)
$n$	Reaction order
$p$	Empirical constant in M-RPM
$P_{CO_2}$	Partial pressure of $CO_2$ (%)
$r$	Gasification reaction rate ( $\text{min}^{-1}$ )
$R$	Specific reaction rate ( $\text{min}^{-1}$ )
$r_1$	Temperature rate 5 min before firing (min)
$r_2$	Temperature rate 5 min after maximum temperature (min)
$R^2$	Regression coefficients
$r_m$	Maximum gasification rate ( $\text{min}^{-1}$ )
$S_0$	Pore surface area ( $\text{m}^2/\text{g}$ )
$t$	Gasification time (min)
$T_a$	Temperature at firing ( $^{\circ}\text{C}$ )

$\tan \delta$	Dielectric loss tangent
$T_b$	Temperature at $b$ time ( $^{\circ}\text{C}$ )
$T_c$	Maximum temperature ( $^{\circ}\text{C}$ )
$T_{corr}$	Correction temperature ( $^{\circ}\text{C}$ )
$w$	Instantaneous mass of the char (mg)
$w_0$	Initial mass of the char (mg)
$W_0$	Weight of dry sample (g)
$W_1$	Weight of sample after heating (g)
$W_2$	Weight of sample after heating at $750^{\circ}\text{C}$ (g)
$X$	Char conversion (%)
$X_{CO_2, t_i}$	Conversion of $\text{CO}_2$ at time $t_i$ (%)
$X_m$	Conversion at maximum gasification rate (%)
$X(t_n)$	Char conversion at reaction time of $t_n$ (%)
$\varepsilon_0$	Initial porosity of the particle
$\varepsilon'$	Dielectric constant
$\varepsilon''$	Dielectric loss
$\theta$	Variable function
$\xi$	Correlation coefficient
$\tau_{50}$	Time required to reach the conversion of 50% (min)
$\Psi$	Structure factor
$\omega$	Width of the curve at $r = r_m/2$

KAJIAN EKSPERIMEN DAN KINETIK CO<sub>2</sub> PENGGASAN BERMANGKIN  
TERHADAP ARANG BIOJISIM MENGGUNAKAN PEMANASAN  
KONVENSIIONAL DAN GELOMBANG MIKRO

ABSTRAK

Penyiasatan terhadap aspek asas proses penggasan telah menunjukkan bahawa kadar penggasan arang, sebagai langkah menghadkan kadar semasa penggasan bahan karbon, memainkan peranan yang penting dalam prestasi keseluruhan penggasan. Projek ini menerokai kaedah untuk memudahkan penggasan CO<sub>2</sub> arang dan meningkatkan kereaktifan arang semasa tindak balas penggasan. Dalam kerja ini, kulit buah kelapa sawit (OPS) dan tempurung pistachio (PNS) telah digunakan untuk menghasilkan arang untuk penggasan CO<sub>2</sub>. Ujikaji awal penggasan CO<sub>2</sub> telah dijalankan pada keadaan isoterma dalam penganalisis Termogravimetri (TGA). Pengaruh pemangkin logam pada kereaktifan penggasan CO<sub>2</sub> arang dikaji. Pemangkin yang digunakan adalah (a) jenis besi (FeCl<sub>3</sub>, Fe(NO<sub>3</sub>)<sub>3</sub> dan Fe<sub>2</sub>(SO<sub>4</sub>)<sub>3</sub>) dicampur pada arang OPS, (b) logam nitrat (KNO<sub>3</sub>, NaNO<sub>3</sub>, Ca(NO<sub>3</sub>)<sub>2</sub>, Mg (NO<sub>3</sub>)<sub>2</sub>) dan Fe(NO<sub>3</sub>)<sub>3</sub>) dicampur pada arang PNS, dan (c) abu tandan kosong kelapa sawit (EFB-abu), sebagai pemangkin semula jadi yang kaya dengan kalium, dicampur pada arang OPS. Keputusan kajian penggasan bermangkin mendedahkan bahawa aktiviti pemangkin tertumpu ditumpukan kepada 5% berat Fe(NO<sub>3</sub>)<sub>3</sub>-OPS, 5% berat NaNO<sub>3</sub>-PNS dan 10% berat campuran EFB-abu dan arang OPS. Beberapa model kinetik termasuk model teras mengecut (SCM), model fungsi pengedaran normal (NDM), model liang rawak (RPM) dan model liang rawak terubahsuai (MRPM) telah digunakan untuk menggambarkan kadar tindakbalas penggasan dan tenaga pengaktifan di samping menentukan parameter kinetik yang lain.